Wave dissipation and balance - NOPP wave project

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LONG-TERM GOALS

Wind-generated waves play a prominent role at the interfaces of the ocean with the atmosphere, land and solid Earth. Waves also define in many ways the appearance of the ocean seen by remote-sensing instruments. Beyond these geophysical aspects, waves also affect human activities at sea and on the coast. The long-term goals of this research are to obtain a better understanding of the physical processes that affect ocean surface waves and their interactions with ocean currents and turbulence, the atmosphere, seismic waves, sediments and remote sensing systems, and to improve our forecasting and hindcasting capacity of these phenomena from the global ocean to the nearshore scale.

OBJECTIVES

- Observe and parameterize the dissipation of ocean waves due to breaking or wind-wave interactions
- Advance spectral wave modeling at all (global to beach) scales in a unified framework, in terms of parameterization and numerical developments
- Help the application of wave models to new problems (upper ocean mixing and surface drift, use of seismic noise data, air-sea gas exchange ...) and use these applications for feedback on the wave model quality

APPROACH AND WORK PLAN

By combining theoretical advances with numerical models, remote sensing and field observations, we investigate the physical processes that affect wind-generated ocean gravity waves, and provide constraints on their parameterization in spectral models. The various dissipative processes that contribute to the spectral wave evolution are isolated by considering geophysical situations in which they are dominant: the long-distance swell propagation in the case of air-sea friction, the evolution of swells on shallow continent shelves in the case of bottom friction, the energy level in the spectral tail in the case of cumulative breaking effects, and the breaking statistics of waves. These require the

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acquisition of new data using stereo-video techniques, for the spectral levels of waves of 1 to 10 m wavelength, and the statistics of whitecaps. The full model is then confronted to a wide range of observations starting from global altimeter, SAR and buoy data. Alvise Benetazzo performed the calibration of the stereo system and the reconstruction of sea surface geometries. The determination of the water velocities from the video data is performed by Francesco Fedele and students at Georgia Tech., and the spectral analysis and whitecap detection is performed by students at Ifremer, under the supervision of Fabrice Ardhuin. All the wave modeling effort at Ifremer (theory, parameterization and calibration) is performed by Fabrice Ardhuin and Fabien Leckler.

In the coming year we will finally combine the analysis of whitecap data with the 3D surfaces to refine estimates of breaking front length statistics. We will also take into account the recent analysis of short wave data by García-Nava et al. (2012) and Ardhuin et al. (2012) and try to compensate for the weak variability of wave-supported stress in parameterization TEST451. All this will also be performed with the multiple DIA parameterization for wave-wave interactions (Tolman, 2009).

WORK COMPLETED

Wave model parameterizations

Wave breaking: We have been working from the two parameterizations of breaking dissipation that we have developed, one based on a threshold in the saturation level (Ardhuin et al., 2010), hereinafter TEST441,, following Banner and Morison Banner and Morison (2010), and the other by Filipot and Ardhuin (2012), hereinafter TEST500, based on the extension to any water depth of the depth induced breaking parameterization by Thornton and Guza (1983). In particular the TEST500 has been modified to make a consistent use of breaking probabilities in the cumulative dissipation term: that updated parameterization is called TEST570.

Swell dissipation: An unwanted artefact of the TEST441 parameterization was a very peaked distribution of wave heights around 2 m, associated with the overestimation of smaller wave heights and underestimation of higher wave heights. That effect was found to be related to the threshold in the disspation rate of swells when going from a laminar to a turbulent boundary layer. A correction of that effect was introduced by smoothing the transition, giving a new parameterization TEST451.

Bottom friction: The parameterization by Ardhuin et al. (2003) based on data of the 1999 SHOaling Waves EXperiment (SHOWEX) has been generalized to be applicable also to relatively coarse bottom material (gravel). Tests in the English Channel and west coast of France show a generally good behaviour.

Coastal reflection: A spectral parameterization of shoreline reflection has been defined by Ardhuin and Roland (2012) from the reflection measurements of Elgar et al. (1994). The parameterization has been adjusted using directional spreading measurements form over 20 buoys off the U.S. West Coast and Hawaii (from CDIP and NDBC), and estimates of bottom slopes derived from 3” DEMs and 1 m resolution LIDAR surveys.

Overall model validation: using the TEST451 parameterization, a 1994-2012 hindcast has been performed and various parameters have been investigated (Rascle and Ardhuin, 2012). Hanafin et al. (2012) has also focused on the largest sea state measured in that time period.

Data analysis

Swells: Husson et al. (2012) have extended the method developped by Delpey et al. (2010) for swell tracking and used it to reduce errors on SAR-derived swell parameters. These swells have been shown to be highly coherent with seismic noise records, that give a complementary extension to very long swell perids. Seismic noise: Based on the numerical noise mode of Ardhuin et al. (2011), Obrebski et al. (2012) have explained how loud seismic noise events can be associated with relatively moderate sea states. That understanding has been further exploited by Ardhuin et al. (2012a) to propose a generic method for estimating ocean wave spectra from seismic noise data.

Implementation in WAVEWATCH III

Several items have made their way to the trunk of the NCEP subversion server

- the latest TEST451 parameterization: now used in operations at NOAA/NCEP.
- The revised SHOWEX bottom friction parameterization
- the implementation of coastal reflection on triangular mesh grids.

others are ready to be integrated in the trunk:

- an interface to the IOS tidal analysis software (Foreman et al., 2009), allowing water levels and currents to be defined from tidal constituents.
- a data assimilation procedure based on SAR-derived swell fields.

While others are still being tested:

- an upgrade of the multi-grid system allowing two-way nesting between regular grids and triangle-based meshes.
- a parameterization of infragravity wave generation at the shoreline

RESULTS

Swell dissipation and global wave hindcasts and forecasts. The simple modification from TEST441 to TEST451 gave the largest improvement of the last 4 years, in global wave heights results, with local rms error reductions up to 30%, in the central pacific, and a global average of 5% in rms error reduction. Model errors and impacts of the new parameterization are shown in figure 1.

Coastal reflection. Reflection was verified to considerably improve directional spreading results from the wave model, and also produce more accurate estimates of the sources of seismic noise. Figure 2 shows a small part of our unstructured US West Coast grid, with a typical wave field for January 2008, and time series of wave height and directional spreading in Monterey bay. Without reflection (brown squares) the model severely understimates the measured directional spreading (black line).

Pros and cons of the TEST451 parameterization

It was found that spectral moments m_0, m_2, m_3, m_4 were very accurately reproduced with a clear improvement compared to parameterizations based on WAM-Cycle 4, the same is true for directional spreading. We have however, identified several shortcomings:

- The spectral tail level at frequencies above 0.4 Hz, is probably a bit too high

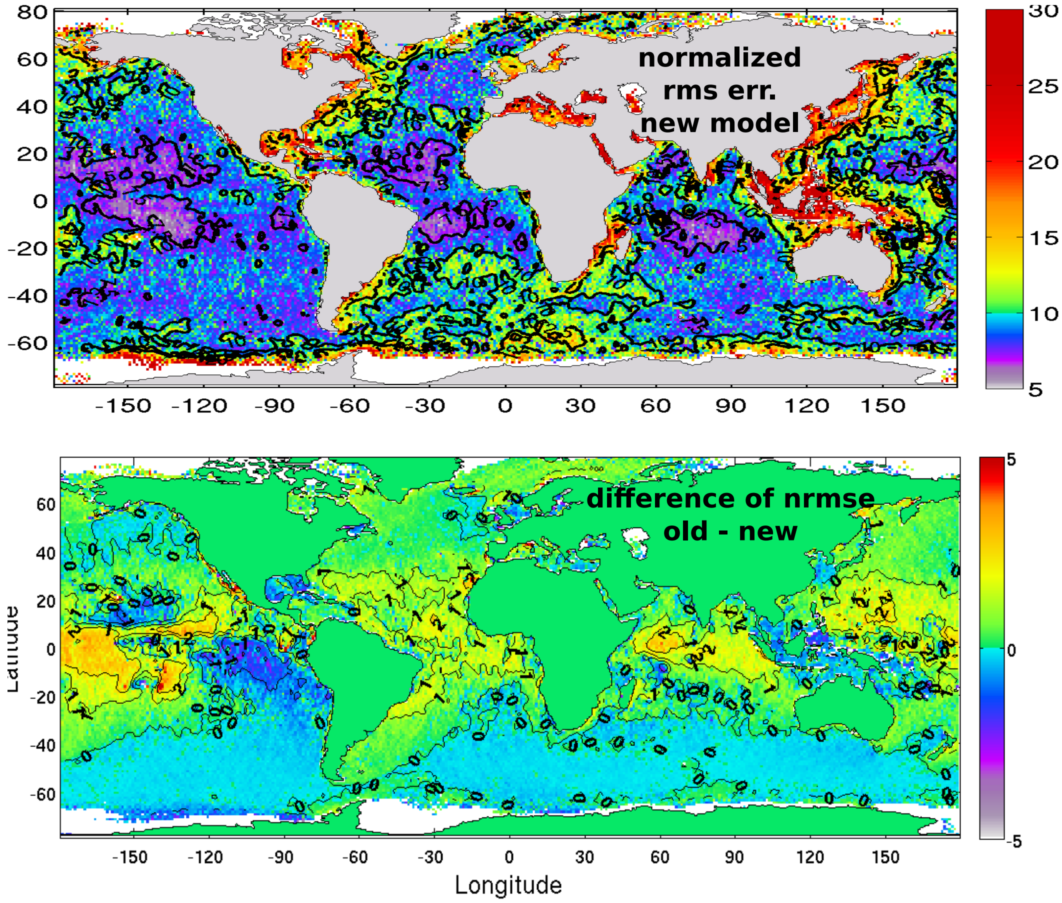

Figure 1: Top: normalized r.m.s. error (NRMSE) of new model parameterization TEST451 for the year 2009, against altimeter data. Bottom: difference in NRMSE between TEST441 and TEST451. In orange areas the improvement exceeds 2 percentage points, which is a relative improvement that typically exceeds 20%.

- The variability of the directional spreading is not well represented for frequencies above 0.4 Hz: this is based on second order pressure records from Duennebier et al. (2012) that we have re-analyzed Ardhuin et al. (2012) based on second order wave theory in a compressible ocean Ardhuin and Herbers (2012).
- The wind stress computed via the modified Janssen parameterization appears to be a function of wind speed only, and does not vary with wave age as it probably should.

These findings are now being used to revise TEST451 into a newer parameterization and also to re-tune this parameterization using now a multiple-DIA (Tolman, 2008).

IMPACT AND APPLICATIONS

The combined use of seismic data and numerical wave models offers new opportunities for investigating the Earth structure (tomography) and observing the swell climate in regions where no buoys are deployed. Extending that work to underwater acoustic noise has revealed important details in the variability of directional spectra at wave frequencies around 0.5 Hz.

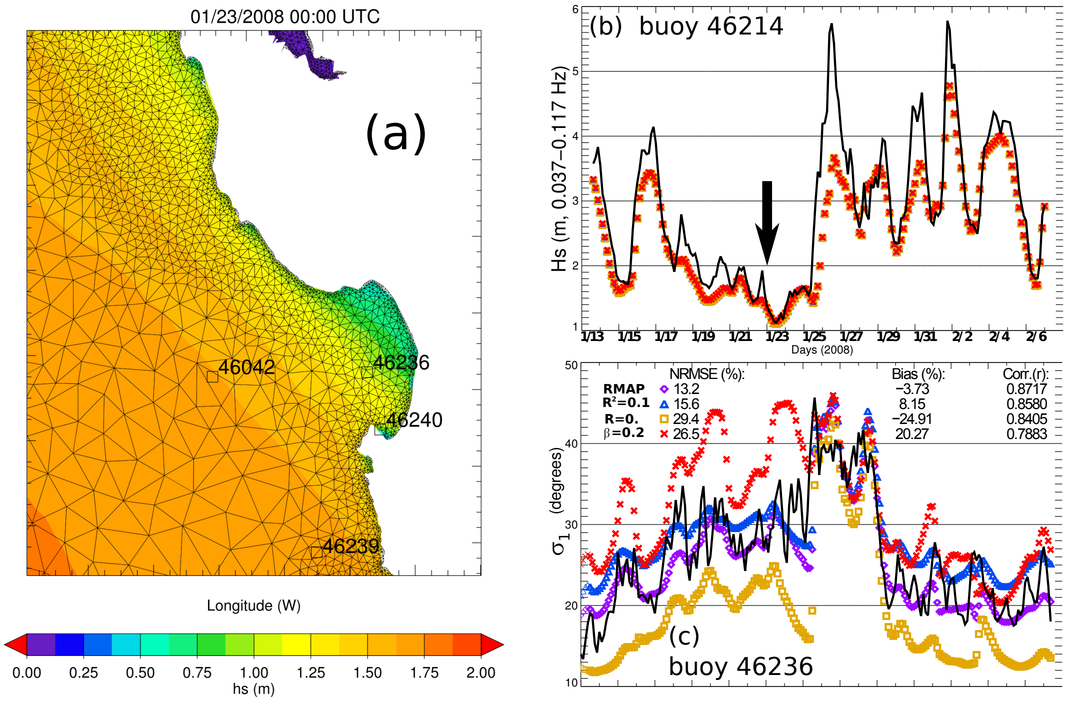

Figure 2: Model results with different reflection parameterizations for 30 days in 2008 based on the unstructured U.S. West Coast grid. (a) Map of modeled significant wave heights showing buoy locations (b) Time series of significant wave height over the frequency range 0.037 to 0.11 Hz, (c) directional spread at buoy 46236 – in Monterey bay – over the same frequency range. The observations are shown with the solid line, and the different model results with different symbols. Namely, the model based on the 3" DEM slopes, multiplied by two, is shown with purple diamonds, whereas the model with a constant 0.1 reflection coefficient is in blue and the model without reflection is shown with orange squares. A constant beach slope of 0.2 gives the results shown with red crosses. The narrow frequency range used here was designed to remove large directional spreads when a wind sea and swell from different directions are present at the same time.

National Security Improving wave forecasts are relevant to a variety of denfence applications. The most dramatic improvement brought in the operational models by the preasent work is an improved representation of swells which are most relevant for amphibious operations.

Quality of Life The transport of contaminants in the nearshore ocean is largely driven by waves. The capability and understanding of this driving process in three dimensions will certainly lead to improved water quality models.

TRANSITIONS

As mentionned above, operational wave models at NOAA/NCEP have been switched from the paramterization by Tolman and Chalikov (1996) to the TEST451, only 3 months after the parameterization had been adjusted. This shows the amazing capability brought about by the new way of developing model frameworks at NCEP using outside contributions on the same subversion server. We will continue helping NOAA/NCEP and others in testing and implementing these parameterizations.

At present a 19-year reanalysis database has been made available to the public (http://www.tinyurl.com/iowagaftp). NCEP has been using the new parameterizations for operational global and regional forecasting since May 2012. Operational implementation for the Great Lakes is also ready.

RELATED PROJECTS

The present "Ocean Waves Dissipation and spectral Balance" (WAVE-DB) shares many of the objectives of the the Integrated Ocean Waves for Geophysical and other Applications (IOWAGA) project, funded by the European Research Council. As a result, results from both projects are reported on the same web pages, where the contribution from each is clearly identified. Whereas WAVE-DB is focused on the development of stereo-video techniques and numerical wave modeling, IOWAGA allows allows a broader perspective with work on remote sensing and seismic noise, which allow a more informed calibration of the numerical wave model. Finally, the WAVE-DB activity is also benefiting from the GLOBWAVE project, funded by the European Space Agency and the French Space Agency to facilitate the use of satellite remote sensing data of ocean waves.

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